NURSERY STOCK REQUIREMENTS FOR OAK PLANTING IN UPLAND FORESTS [1/]

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In forest nurseries in the United States, oaks (*Quercus* spp.) account for about 7 percent of total hardwood production or nearly two million trees per year (Abbott and Fitch 1977). Given these statistics and the long history of growing oaks in nurseries, we might expect oak planting in the oak-hickory region to be a well-developed art.

However, successful oak plantings are rare and the literature is replete with reports of failures in various regions (Johnson 1976, Hilt 1977, Olson and Hooper 1972). Such failures are primarily due to the slow growth of planted trees rather than to mortality *per* se. This is especially true on forest sites where planted trees have to compete with established vegetation. A solution to this problem is urgently needed because of the difficulty and uncertainty of naturally regenerating oaks in many situations (Clark and Watt 1971, Sander et al.1976). The magnitude of the problem is further emphasized by the size of the oak-hickory forest, the largest single forest type in the United States.

Much of the effort in solving the oak planting problem in the oak-hickory forest has focused on how to make the outplanting environment more favorable for oak seedling growth. Few studies have focused on the nursery environment as a source of the problem until recently. Now there is evidence that at least some facets of the problem originate and can he solved in the nursery.

Although we still do not know how to ensure the success of an oak planting, the nursery manager can act to ensure *improvement* in the field performance of planted oaks. In this context, the following discussion will focus on the significance of size and physiological quality of oak nursery stock, and how these factors are influenced by the nursery environment.

SPECIES DIFFERENCES

Oaks are difficult to establish by planting largely because of their slow shoot growth. Shoot elongation is also periodic, occurring in distinct flushes that alternate with resting (quiescent) periods. In contrast, some hardwoods such as yellow-poplar (*Liriodendron tulipifera* L.) and black cherry (*Prunus serotina* Ehrh.) grow continuously through the growing season. Small oak seedlings, either planted or natural, typically produce only one flush per growing season under field conditions. Conversely, larger oak seedlings and sprouts may produce several flushes per growing season (Johnson 1979).

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Although the general pattern of shoot elongation in all oaks is similar, not all species are equally slow growing nor equally difficult to establish. For example, in the Michaux Quercetum in Pennsylvania, wide variations in 13-year height growth was observed among the 13 species compared (Garrett and Kettlewood 1975). The faster growing species included pin oak (*Quercus* palustris Muenchh.), shumard oak (Q. *shumardii* Buckl.), and northern red oak O. *rubra* L.); among the slowest growing species were bur oak (Q. *macrocarpa* Michx.) and post oak (Q. *stellata* Wangenh.). Northern red oak height growth was more than twice as fast as that of white oak (Q. *alba* L.) and about 60 percent faster than that of black oak (Q. *velutina* Lam.) in a 7-year Tennessee direct seeding study (Mignery 1975). In an 8-year Missouri study, planted northern red oak and scarlet oak (Q. *coccinea* Muenchh.) seedlings grew faster in height than black oak and white oak (Johnson 1980a).

Different species of oaks also exhibit different growth rates in the nursery. For example, Farmer (1980) found that the rate of dry weight increment (relative growth rate) and height growth in northern red oak and chestnut oak (Q. *prinus* L.) was greater than in white oak and bear oak (Q. *ilicifolia* Wangenh.). The faster growing species were associated with higher leaf areas, higher shoot-root ratios, and higher rates of relative leaf area expansion than the slower growing species. However, net assimilation rate (i.e., rate of dry matter increment per unit leaf area) of all four of these species was about the same. Thus, differences in the early development and expansion of leaf area may account for much of the interspecific variation in growth of juvenile oaks (table 1).

SIZE OF NURSERY STOCK

Many oak planting failures can probably be attributed to inadequate size of nursery stock. Regardless of species, small oak seedlings have little potential for rapid shoot growth even under optimal growing conditions (Johnson 1979, Farmer 1975b). Large seedlings provide the necessary carbohydrate reserves for initiating adequate root, shoot, and leaf area development needed to sustain satisfactory growth under field conditions. For most upland oak species, a reasonable size guideline for producing plantable oak stock for most upland sites would be a minimum caliper of 8 mm (10/32 in) measured 2 cm (1 in) above the root collar and a minimum shoot length of 50 cm (20 in) (Farmer 1975b, Foster and Farmer 1970, Johnson 1976).

UPPER LIMITS OF SEEDLING SIZE

Shoot length of oak nursery stock should probably be no longer than about 1 m (3.3 ft) for use in reforestation. If tops are larger than this, shoot:root ratios may be excessive. Roots are usually pruned 20 to 25 cm below the root collar to facilitate field planting. Thus, while root mass may vary little, shoot mass will vary widely for trees 50 to 100 cm tall. The effect of this variation has not been determined and consequently an optimum shoot:root ratio (after root pruning) has not been defined. However, we might reasonably expect this optimum to vary by species. Droughty planting sites might require nursery stock with lower shoot:root ratios than more moist sites would require.

Shoot pruning is one way to reduce large seedling tops to facilitate handling and to reduce excessive shoot:root ratios. However, shoot pruning has been shown to reduce root and shoot growth in several oak species including northern red oak (Johnson 1979, Larson 1975, Wendel 1980, Farmer 1975a), pin oak (Lee et al. 1974), and white oak and sawtooth oak (Q. acutissima Carruthers? warmer 1975). An exception may be scarlet oak which in one study (Lee et al. 1974) produced more root growth after top pruning. The latter finding suggests that root-shoot relationships may markedly differ among oak species. However, more research is needed on how the timing and amount of shoot removal of dormant oak stock affects subsequent growth. Except for scarlet oak, the safest procedure would seem to be to control shoot growth in the nursery by undercutting and manipulating fertilization and irrigation schedules rather than by shoot pruning.

Nurseries in the Northern States may not be able to grow oak stock to a plantable size in one growing season. Nurseries a little further south (e.g., the southern part of the Lake States) may find that their 1-0 red oak stock is too small and their 2-0 stock is too large. In this case, undercutting of roots the first year about 10 days after the completion of the first flush will usually inhibit further flushing that year. At the end of the second growing season, seedlings will then have, on the average, one flush more than 1-0 stock and 1 or 2 flushes less than 2-0 stock. Undercutting will also create a more fibrous root system.

IRRIGATION AND FERTILIZATION

Even moderately high soil water potentials of -600 kPa (-6 bars) may inhibit flushing and root elongation in young oaks (Larson 1974, Teskey 1978). Consequently, soil moisture must be maintained at relatively high levels to promote flushing. Conversely, irrigation water can be withheld to prevent excessive shoot growth.

Variability in the application of irrigation water even within the same irrigation unit can also cause variability in the growth of oak seedlings. This has been observed at the George O. White State Forest Nursery where red oaks in the center of irrigation units may be about 50 percent taller than those on the outside edges of these units. This variation occurs because the spray from the irrigation lines on each side of a unit overlap near the center. Similar variation in nursery environment may exist in relation to nutrient gradients, surface drainage patterns, and other factors. Although each nursery will be different in this respect, there may often be opportunities for manipulating growth of oak stock without altering the usual management routine.

Adequate mineral nutrition is important for maintaining rapid growth of oak seedlings (table 2). Nitrogen is particularly important in promoting flushing (Gall and Taft 1973, Farmer 1975b). However, excessively high soil nutrient levels may depress the development of a mycorrhiza that is artificially introduced into the seedbed.

Table 2. Soil fertility standards for five oak species [1/]

Species	pH range	Total N	Available P_2O_5 per acre	Available K_2O per acre	Base exchange capacity	Exchangeable Ca	Exchangeable Mg
		Percent	Pounds	Pounds	Me./100 grams [2/]		
White and bur oak	5.5-7.3	.20	100	250	10.0	5.0	2.0
Pin, northern red and black oak	5.0-6.0	.12	70	200	7.0	2.5	1.0

1/ Source: Williams and Hanks 1976; Wilde 1958.

2/ Milliequivalents per 100 grams.

PHYSIOLOGICAL QUALITY OF OAK NURSERY STOCK

Oak nursery stock of the size outlined previously has the potential for relatively rapid shoot and root development (Farmer 1975b). Unfortunately, even with large stock, this potential has seldom been realized in field plantings. Recent research has indicated that poor physiological condition of nursery stock may be the cause of these failures. Related problems and possible solutions to reduced physiological quality are discussed below.

COLD STORAGE AND PLANT WATER STRESS

A conventional cold storage environment may reduce physiological quality of oak nursery stock because of high shoot water stress that can develop in storage (Webb and von Althen 1980). This water stress is associated with poor root growth. Even when storage temperatures are within the usual operating norms of 2 to 5° C (36 to 41° F), shoot dieback may occur, resulting in reduced shoot growth, leaf areas, and root regeneration (Johnson et al. 198-).

To eliminate deleterious water stress, Webb and von Althen (1980) recommended that fall-lifted stock be completely and tightly enclosed in Kraft bags lined with polyethylene. They also recommended that storage temperature be maintained at 0.5 C (1 F) and relative humidity at 70 to 85 percent. Although antitranspirants have not been widely used to prevent storage dehydration, one study (Lee et al.1974) illustrated their effectiveness on scarlet oak. Seedlings whose stems were treated with antitranspirants had greater root regeneration after planting than untreated seedlings had. Late-spring lifting is another alternative to the liability of long-term cold storage necessitated by fall lifting.

Fall planting is yet another way to avoid long cold-storage periods. However, substantial winter shoot dieback of fall-planted English oak (Q. robur L.) (Johnson 1981) and black oak (Dixon et al.1981b) in Missouri has been noted. Similarly, severe dieback of oak stock healed-in over winter in the nursery bed is a common phenomenon. Despite these diebacks, an Indiana study showed no significant difference in field growth between healed-in fall-lifted and spring-lifted 1-0 red oak stock (Williams 1963). It would nevertheless appear expedient to avoid fall planting and long-term healing-in of oak nursery stock to ensure the best possible initiation of root and shoot growth.

CARBOHYDRATES, LEAF RETENTION, AND IRRIGATION

As seedling size increases, the capacity for carbohydrate storage increases. Thus, seedling size and physiological quality are not mutually exclusive attributes. Farmer (1978) showed that root systems of oaks are powerful physiological sinks for carbohydrates, especially starch. He found that most starch and sugar accumulated in roots between mid-September and early November in Tennessee.

Because high starch content apparently is an important characteristic of oak seedling quality, Farmer (1978) suggested that cultural efforts in southeastern nurseries should concentrate on: (1) producing large seedlings with large root storage capacities for carbohydrates; and (2) controlling irrigation to stop shoot elongation by mid-September to avoid frost damage to non-hardened, late shoots but maintaining fall moisture adequate for good leaf retention until November.

Fall leaf retention may be an important factor in raising oak nursery stock not only for maximum carbohydrate accumulation but also to maximize the export of growth regulators from leaves to roots. Larson (1978) concluded that late-season export of carbohydrates to roots is largely completed by the end of September but that other substances (possibly cytokinins) necessary for growth may continue to be exported for a few weeks. Defoliation of northern red oak seedlings as late as October 15 resulted in reduced growth of shoots and roots the following spring (Larson 1975). It was concluded that fall defoliation of nursery seedlings can be detrimental to red oak and possibly other species.

BUD VIABILITY

Buds are obviously important in determining potential leaf area and photosynthesis. However, buds also play an important role in the initiation of root growth (Lee et al.1974, Farmer 1975a). Disbudded pin oak seedlings initiated only about one-fourth the number of roots that intact seedlings did (Lee et al.1974), and disbudded northern red oak seedlings initiated fewer roots than intact seedlings in eight out of ten monthly tests (Larson 1975). The negative effect reported associated with shoot pruning may thus be largely the result of bud losses.

Substances exported from viable buds also influence the initiation of cambial growth and thus the formation of the new growth ring (Wareing 1951). Because most if not all water transport in the stem occurs in the new ring (Zasada and Zahner 1969), the water transport system of an oak may be seriously impaired when buds are not fully functional. Consequently, failures of buds may account for much of the commonly observed shoot dieback in juvenile oaks.

Because of their importance to spring growth, buds of dormant oak seedlings should be carefully protected against both physical and physiological damage during lifting, handling, storage, and shipping. Conventional lifting equipment may damage stems and buds of large oak seedlings, and at least one nursery uses a lifter specifically designed to eliminate this problem (Brenneman 1978). Buds can also be damaged in other phases of nursery handling including the stacking of bundles on cold storage racks and handling during shipping. This points to another potential advantage of the complete enclosure method of packaging nursery stock which can protect trees from both physical damage and dehydration.

MYCORRHIZAE

Inoculation of nursery beds with a suitable ectomycorrhiza can result in larger oak seedlings, increased root and leaf surface area, and increased drought resistance of seedlings (Marx 1979b, Dixon et al.1980 and 1981a). Preliminary tests with the ectomycorrhizal fungus _Pisolithus tinctorius_ (Pers.) Coker and Couch have been particularly promising on northern red oak (Marx 1979b), white oak (Marx 1979a), and black oak (Dixon et al.1981a).

Nursery beds can be inoculated with certain isolates of _Pisolithus tinctorius_ by incorporating the inoculum (vegetative mycelium mixed with peat and vermiculite) into the upper 20 cm (8 in) of soil at a rate of about 1 liter per m^2 (0.1 quart per ft^2) (Marx 1979a). However, before inoculation, nursery beds should be fumigated with methyl bromide. For white oak and other fall-germinating species, inoculum should be incorporated into the soil in the fall; for spring-germinating species, inoculum should be incorporated in the spring.

Nursery soils that are excessively high in available nutrients may discourage mycorrhizal infection of oaks (Dixon et al.1981a, Ruehle 1980). However, normal nursery fertility standards should be compatible with mycorrhiza requirements (Dixon et al 1981a). Although not commercially available as of this writing, Pisolithus tinctorius inoculum is expected to be available soon in quantities required for nursery application. Also, other ectomycorrhizal associations in oaks may become useful to the nurseryman in the future (Garrett et al.1979, Marx 1979b).

TRANSPLANTING AND UNDERCUTTING

Transplanting oak seedlings in the nursery may increase stock quality. Based on a greenhouse study (Johnson et al.198-), root growth of 1-1 northern red oaks was twice that of 1-0 stock of the same shoot size and leaf area. In a Wisconsin study, 1-1 transplants grew faster than 1-0 seedlings when planted in upland clearcuts (Johnson 1976). Even older transplants have been grown in North Carolina where Brenneman (1978) reported that large 1-2 or 2-2 oak transplants with well-developed root systems are necessary for satisfactory field growth.

One explanation for the superior performance of transplants may be their more fibrous root system and thus larger number of sites for the initiation of new root growth. In addition, during the second year and later, lateral branches develop on the stems. Consequently, transplants have more buds and leaf areas than branchless 1-0 stock has even when total heights are the same.

Limited experimental work indicated that undercutting may be a useful and more economical method than transplanting for creating seedlings with the desirable characteristics of transplants. Undercutting also is a more flexible tool for the timely control of shoot elongation.

GROWING OAKS IN CONTAINERS

Although fewer than 1 percent of all container-grown seedlings in North America are hardwoods (Tinus 1978), container-grown oaks have some advantages over bare-root oaks.

When the oak is grown in an open-bottomed container, its root system is altered from the normal form (a large single taproot with relatively few laterals) into a dense fibrous root system with a taproot limited in length by the container depth. The formation of lateral roots is stimulated by "air-pruning" of roots as they emerge into the airspace beneath the open-bottom container. The result is a compact root system or "plug" that contains many root tips from which new roots can be regenerated. The root plug remains in the protective environment of the container until it is planted. Oak seedling growth increases with increasing container size, hut the containers probably shouldn't be larger than 750 ml (45 in-') in volume and 25 cm (10 in) in depth.

In a greenhouse study, container-grown northern red oaks transplanted to root observation chambers grew faster and developed larger root and leaf areas than bare-root stock did (Johnson et al 198-). In addition, a field study of black oaks planted in a Missouri clearcut showed that container stock had higher leaf areas, less shoot dieback, and better root growth than bare-root stock (Dixon 1979). Mycorrhizal inoculation with Pisolithus tinctorius has also been shown to be more effective in containerized than in bare-root black oak (Dixon et al.1981b).

Procedures for growing oaks in containers have been outlined in detail (Tinus 1980, Tinus and McDonald 1979). Other recent developments in oak planting, cultural methods, and research on oak seedling growth have been summarized elsewhere (Johnson and Garrett 1981, Johnson 1980b).

PLANNING FOR THE PRODUCTION OF LARGE, HIGH-QUALITY OAK STOCK

Because of the many considerations in producing large, high-quality oak nursery stock, the nursery manager may want to reassess his present management system for oaks. Of primary consideration is the desired species and the length of nursery growing season. These two factors will determine the length of the production period and whether or not transplanting or undercutting is appropriate.

Other considerations include optimizing the nursery bed environment through seedling density control, adequate fertilization, and appropriate manipulation of irrigation schedules. In addition, mycorrhizal inoculation may soon be a viable option.

Lastly, control of the "transition" environments during lifting, handling, and cold storage is essential if benefits from an improved growth environment are to result in improved field growth (fig. 1).

FIELD PERFORMANCE

Planting of oaks in upland clearcuts should be made during the first spring after overstory removal. Oaks can also be planted under mature stands before clearcutting. However, clearcuts provide a relatively favorable environment for planted tree growth the first year after overstory removal because competition is light to moderate. Thus, if the nursery stock is delivered to the field in good physiological condition, it will be able to continue developing in a relatively favorable light and moisture environment.

Spring planting of oaks is safer than fall planting because it avoids frost heaving and shoot dieback that can occur before spring growth. Planting should be done about 10 to 14 days before the onset of growth of indigenous vegetation. This will minimize the length of the dormancy period in the field during which cold soils may limit water uptake and a desiccating atmosphere may cause shoot and bud dehydration.

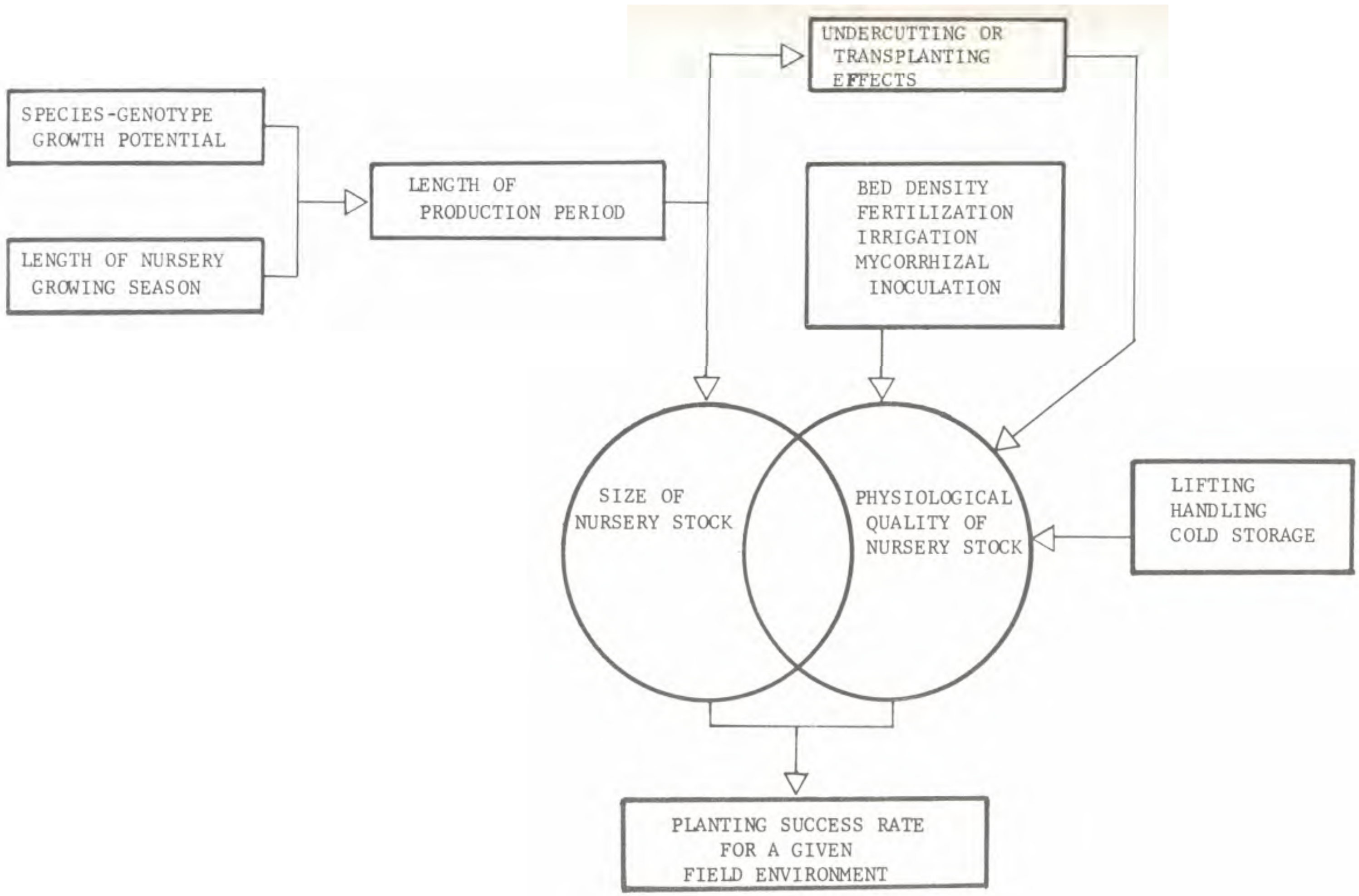

Figure 1. Relationship among nursery factors that influence planting "success" rate of oaks

The first flush of growth of an oak seedling or transplant after outplanting is largely predetermined by environmental events that precede planting. Barring damage from frost or biotic agents, the field environment has little influence if soil and air temperatures and soil water are within the range of normal spring conditions. Because growth of juvenile oaks is potentially exponential, subsequent growth depends heavily on the growth (particularly leaf area development) of the first flush. In plantings on forest sites, the failure of the first flush to produce adequate shoot and leaf growth and correlated root regeneration dooms most planted oaks to recurrent shoot dieback and permanent suppression (fig. 2).

To perform adequately on upland forest sites, planted oaks must maintain height growth equal to that of their competitors. With no weed control, height growth of dominant competing vegetation in oak clearcuts in the Missouri Ozarks averages about 45 cm (18 in) per year during the first decade after clearcutting. However, applying herbicides to stumps of unwanted species can substantially reduce competition and thus increase the number of planted oaks that attain codominant or larger status during the first decade.

Defining "success" criteria before planting will be necessary for determining the type of planting stock needed and for evaluating the performance of oaks planted among competing woody vegetation. For a given type of nursery stock and planting site, "success" probabilities for planted trees can be estimated from field trials (Johnson 1976). These probabilities can then be used to determine the number of trees per acre required to supplement natural regeneration to attain "adequate" stand stocking at some future time (i.e., 10 or 20 years) (Sander et al.1976). Implementing this or similar methods of oak interplanting will require more information and attention to silvicultural detail than required in most current methods of plantation establishment.

The proportion of planted oaks that are "successful" in clearcuts may vary widely, depending on the species planted, composition and density of competitors, site, weather, insect and wildlife damage, and other factors. In a Wisconsin clearcut, the number of planted 1-1 northern red oaks required to produce, with a probability of 0.80 or greater, at least one "successful" tree after 8 years ranged from 5.1 to 11.4, depending upon defined "success" criteria (Johnson 1976). However, in a West Virginia study, it was estimated that from 30 to 50 percent of planted 2-0 red oaks would reach maturity based on the number of codominant or larger planted trees in 7-year-old clearcuts of site index 60 to 70 (Wendel 1980). Based on this expectation, 2 to 3.3 trees would have to be planted for every "successful" tree that develops.

For the oak-hickory region, numbers of planted oaks required can thus be estimated from (1) expected success rate of the planted trees and (2) numbers of "successful" planted trees that are needed to make up deficiencies in oak advance reproduction (Sander et al.1976).

An alternative to planting oaks in clearcuts is to underplant in mature stands. This has the potential advantage of allowing the root systems to become well established before the surge of competition growth that follows clearcutting. However, mycorrhizal development may be poor under low light

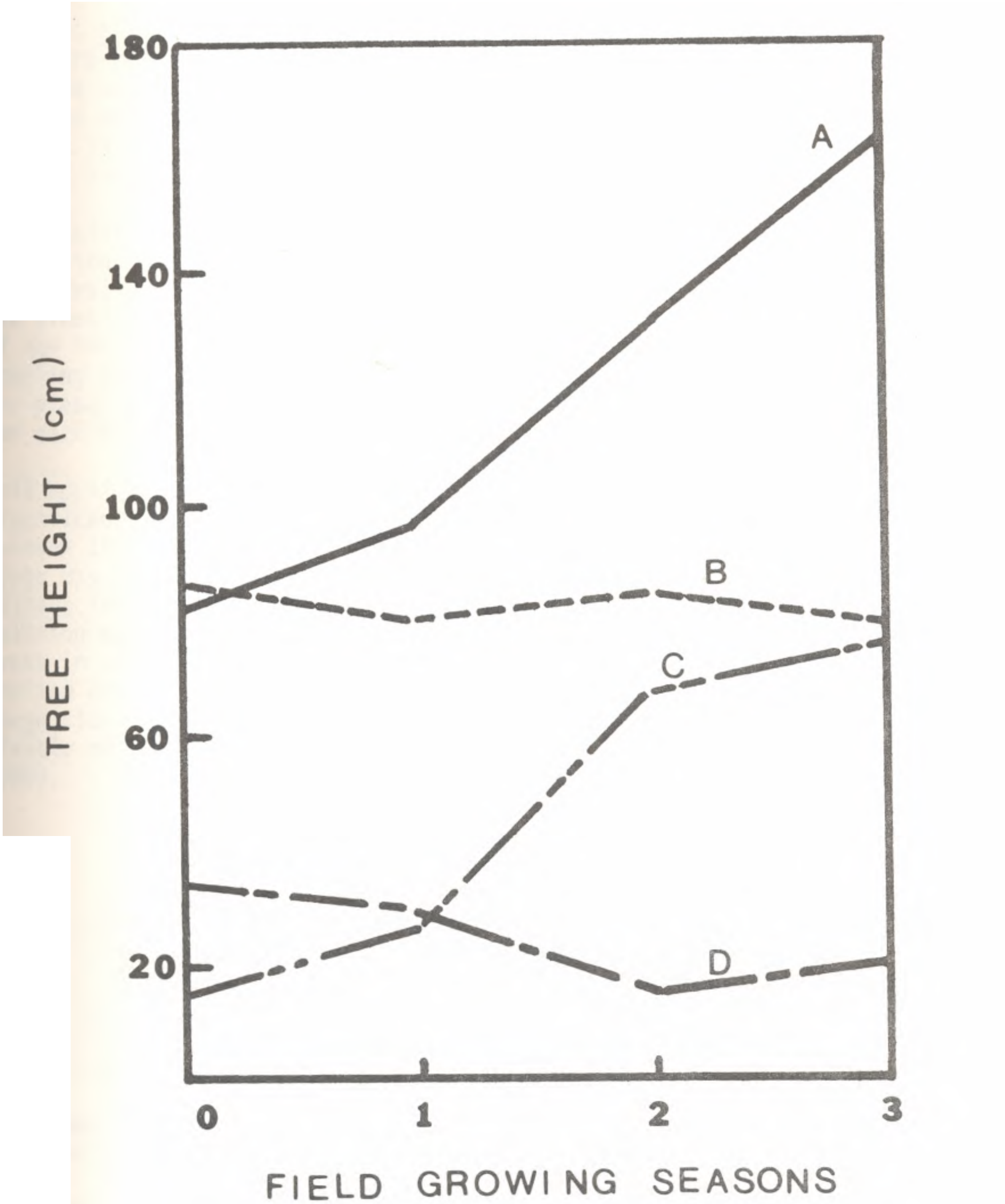

Figure 2.--Three-year growth of four northern red oak seedlings planted in an Ozark oak clearcut. (A. Large (81 cm tall) seedling of apparently good physiological condition at time of planting and sustaining rapid height growth; B. Large (86 cm tall) seedling with first-year shoot dieback characteristic of trees of poor physiological condition; C. Large (78 cm tall) seedling clipped back to 16 cm at time of planting that failed to regain its original height after 3 field growing seasons; D. Small (34 cm tall) seedling that is declining in height due to dieback and suppression. All 4 trees were root pruned 20 cm below the root collar before fall planting.)

(Garrett et al.1979). Both overstory and understory density control may therefore be required to obtain the light and soil moisture necessary for adequate development of planted trees before clearcutting. Oak underplanting thus has much in common with the shelterwood method of natural regeneration (Sander 1979). Studies in oak underplanting that involve overstory density control and time of removal are currently underway in several regions.

Site quality is also an important consideration in oak planting. For timber production, oak planting will probably not be economically feasible nor silviculturally necessary on site indexes below about 60. At the other extreme, oak planting on sites above site index 75 may also not be practical because of the intense competition which may exceed the inherent upper limit of oak seedling growth. However, a better estimate of the upper site quality limit for planting oaks will depend on knowing the upper limit of shoot elongation for each species.

Soil application of fertilizers at time of planting has been shown to significantly increase height growth of planted oaks (Foster and Farmer 1970, Johnson 1980a). Using fertilizers in combination with other cultural improvements may be especially advantageous to shoot growth. Some of the slow-release fertilizers may be particularly beneficial. Similarly, plastic mulching may provide significant benefits if used in conjunction with improvements in stock quality. This has been shown by the response of containerized English oak (Q. *robur* L.) to black plastic mulching--a positive response by large stock and a negative response by small stock (Johnson 1981). However, plastic mulching failed to benefit planted red oaks in West Virginia (Wendel 1980).

SUMMARY

Field performance of planted oaks can be substantially improved through the use of large nursery stock of high physiological quality.

Oak nursery stock for planting on most upland forest sites should have a caliper of at least 8 mm (2 cm above the root collar) and shoots between 50 and 100 cm long.

Management strategies used to grow larger stock will depend in part on species and length of nursery growing season.

Undercutting, transplanting, fertilization, and irrigation can be used to manipulate height growth of oaks in the nursery to achieve size objectives.

High physiological quality of oak nursery stock is related to (1) minimizing plant water stress that develops in cold storage, (2) producing large stock with high carbohydrate reserves, (3) maintaining adequate fall soil moisture to favor late leaf retention, (4) protecting buds of dormant seedlings from desiccation and mechanical injury, (5) infecting stock with an effective ectomycorrhiza and (6) undercutting or transplanting to create a fibrous and compact root system with a high capacity for root regeneration, shoot elongation, and leaf area development.

Growing oak seedlings in containers is an alternative to bare-root stock for producing large seedlings of high physiological quality.

In oak-hickory forests, numbers of planted trees required to assure complete site utilization by desirable species can be estimated from (1) expected "success" rate of the planted trees and (2) numbers of "successful" planted trees that are needed to make up deficiencies in natural reproduction.

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